22

Research Report

Assessing Irrigation Performance with Comparative Indicators: The Case of the Alto Rio Lerma Irrigation District, Mexico

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and
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International Water Management Institute

Research Reports

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Contents

Summary

In addition to using process indicators, the International Water Management Institute (IWMI) suggests using a minimum set of comparative indicators to assess hydrological, agronomic, economic, financial, and environmental performances of irrigation systems. The aim of applying comparative indicators is to evaluate outputs and impacts of irrigation management practices, interventions across different systems and system levels, as well as to compare various irrigation seasons and technologies with one another. The application of comparative indicators should provide system managers, researchers, and policy makers with information on differences in performance and, as a consequence, enable them to identify gaps in irrigation management policies. Generally, process indicators are used to assess actual irrigation performance relative to system-specific management goals and operational targets. It is believed that, in comparison with process indicators, the application of comparative indicators requires data collection procedures that are less time- and resource-consuming.

To test their applicability and usefulness, comparative indicators were applied to the Alto Rio Lerma Irrigation District (ARLID) in Mexico that has a gross command area of 113,000 hectares, as well as to two modules within the district. The results and data collection procedures of the comparative indicators were compared with those of a small set of process indicators.

Performance assessment of ARLID with comparative indicators points to irrigation management under conditions of relatively abundant water availability, planned irrigation depths that are high relative to crop requirements, economic outputs per unit of water and land that are favorable compared to other districts, full recovery of O&M costs, and overexploitation of the aquifers.

The application of process indicators at district and module levels, as well as at the level of selected canals and fields, provided good insight into the processes and dynamics of system management. The results indicate that actual water allocation at the district level closely follows the volumes concessioned to the modules and that there are few problems related to timeliness and spatial distribution of water delivery within the selected canals. In all cases observed, actual irrigation supply to canals and fields was higher than planned and reported. An important advantage of assessing performance based on process indicators was that it provided an excellent way to better understand the nature and the quality of the data reported by the modules. As these reported data formed the basis of much of the data available at the district level, it proved to be an important element in cross-checking the reliability of these district data, much of which is used to calculate the comparative indicators.

The application of comparative indicators was less time- and resource-intensive than the procedure to collect primary data for the process indicators. Yet, it proved to be more complex than was anticipated. The main reason for this was the need to collect and aggregate data at lower system levels to cross-check aggregated district-level data. In addition, several problems were encountered with the calculation of the indicators. These include the lack of reliable data on non-beneficial ET, flows to sinks, as well as the lack of standardization for the calculation of effective rainfall. Finally, the lack of comparative studies made it difficult to interpret outputs per unit of water and land.

Once these methodological problems have been resolved, the minimum set of comparative indicators will be a useful and cost-effective instrument for monitoring outputs and impacts of irrigation management, as well as for providing a good basis to start correlating type and quality of process performance with comparative performance.

Assessing Irrigation Performance with Comparative Indicators: The Case of the Alto Rio Lerma Irrigation District, Mexico

Wim H. Kloezen and Carlos Garcés-Restrepo

Process versus Comparative Performance Indicators

This research report describes and evaluates the application of IWMI's minimum set of comparative performance indicators to the Alto Rio Lerma Irrigation District (ARLID), located in the Mexican State of Guanajuato, and compares this with the application of a small set of process performance indicators. This study is used to test three hypotheses on the usefulness and applicability of this minimum set of comparative indicators to assess the performance of a large-scale irrigation system:

- Within one system, comparative indicators allow to distinguish between differences in performance across system levels, seasons, and irrigation sources.
- Assessments based on comparative indicators help identify gaps in management policies.
- Unlike process indicators, the application of comparative indicators is not data-intensive and is consequently cost-effective.

Performance indicators were applied for the 1995–96 winter and the 1996 summer cropping seasons to the district as a whole, and to two of the districts' 11 irrigation subunits, the Cortazar and Salvatierra modules. The restricted data set in this report allows a comparison of performance levels over different areas within the system, different cropping seasons, and different irrigation sources (surface water and groundwater). Kloezen, Garcés-Restrepo, and Johnson (1997) discuss a detailed analysis of temporal changes in performance levels in a research report on the impact of an irrigation management transfer program in ARLID, in which 1982–1996 time series data are used.

The objective of using comparative indicators is to evaluate outputs and impacts of intervention in individual systems, compare performance of a system over time, and also to allow comparison of systems in different areas and at different system levels (Molden et al. 1998). This is in contrast to process indicators, which are generally used to assess performance following a goal-oriented model approach. This approach relates actual performance to system-specific management targets relative to goals established by irrigation managers (Small and Svendsen 1990, 1992).[1] Process indicators help system managers to monitor the quality of daily and seasonal operational performance (Murray-Rust and Snellen 1993), but do not allow to assess the importance of irrigation in a given system, at different system levels, in a given season, and with a specific water source relative to other systems, levels, seasons, or irrigation sources.

Numerous studies focus on the definition of a number of process indicators.

[1]Small and Svendsen (1990 and 1992) distinguish this *goal-oriented model* from the *natural system model*, which measures performance more in terms of a system's ability to obtain inputs than in terms of either its outputs, or impacts.

Common indicators defined in literature include:

- Conveyance, distribution, field and application, and project efficiencies (Bos and Nugteren 1990; Molden and Gates 1990; Wolters 1992).
- Reliability and dependability of water distribution (Abernethy 1986; Molden and Gates 1990; Oad and Sampath 1995).
- Equity or spatial uniformity of water distribution (Abernethy 1986; Levine and Coward 1989; Sampath 1988; Sharma, Oad, and Sampath 1991; Molden and Gates 1990).
- Adequacy and timeliness of irrigation delivery (Levine 1982; Abernethy 1986; Molden and Gates 1990; Oad and Sampath 1995; Meinzen-Dick 1995).

Rao (1993) provides an excellent summary of this literature, and many authors have applied one or more of these and other indicators at particular irrigation systems (see for instance, Jurriëns 1996). Beyond doubt, all these indicators have proved to be useful as they provide important information about process operational performance processes of the particular systems where the indicators were applied. However, the indicators mentioned above have shown some limitations to their usefulness and applicability. These limitations include:

- Most authors propose to use different indicators or to use different methodologies or tools to measure the same indicator. Although recent efforts have tried to standardize some process indicators (Bos et al. 1994), proposals for new process indicators or other methodologies to measure indicators are still emerging. As a result, comparisons across systems or over time are hardly possible.[2]
- Process indicators are based on the existence of clearly defined management goals and operational targets. However, in many irrigation systems, these goals and targets are either absent, or are too widely defined and inconsistent with one another (Brewer, Sakthivadivel, and Raju 1997).
- As pointed out by Small and Svendsen (1990), measuring process indicators following the goal-model approach, implies that subjectivity enters the performance evaluation both in the establishment of the goals and targets themselves, and in the way differing goals are weighted. System managers, policy makers, farmers, and researchers might all set different goals and targets, especially in systems where both are not yet (or poorly) defined, or where goals have changed as a result of dramatic changes in, for instance, cropping patterns, water availability, or the political and economic systems.
- Generally, these process indicators address how the input (water) is used, but do not provide information on to what wider hydrological, agricultural, economic, social, and environmental impacts the inputs have led.
- Most of the performance assessment exercises described in literature were done in the context of intensive research programs, often to test new indicators introduced by researchers, rather than proposed by system managers. As a consequence, little is known about how system managers perceive the usefulness of these indicators for daily sys-

[2]See, for example, Oad and Sampath 1995 and Meinzen-Dick 1995.

tem operation, and how easy it is to apply these indicators for day-to-day monitoring purposes.

- Measurement of most process indicators requires complicated data collection procedures. Monitoring systems are normally not set up to collect these required data. As a consequence, applying the indicators requires additional staff, skills, and equipment, which are generally not available within irrigation systems, or which are hard to obtain.

Without pretending to overcome all the limitations mentioned above, IWMI has identified nine comparative indicators that address at least a few of these problems. This minimum set of indicators is based on hydrological, agronomic, economic, financial, and environmental parameters. The aim is to evaluate impacts of management interventions, and to provide a basis for identification of how a system is performing by measuring outputs of irrigated agriculture. This report is one of a series illustrating the application of the IWMI-recommended minimum set of comparative indicators.

To evaluate the experience with applying the comparative indicators as well as the type of information generated with them, several process indicators were added for comparison. The choice of this set of process indicators is based on what system managers in ARLID perceive to be the most important operational targets.

The Irrigation District and Two Selected Modules

The Irrigation District

ARLID was constructed in the 1930s and has a gross command area of 112,772 hectares. It is located in the State of Guanajuato, central Mexico. The district is located in the upper reach of the 48,215 km^2 Lerma-Chapala water basin, which crosses five States and serves nine irrigation districts as well as the huge lake Chapala, near Guadalajara. The total catchment runoff of this basin is approximately 4,740 million cubic meters (MCM), of which on an average, 43 percent (or 2,020 MCM) is made available to the irrigation districts, 30 percent to small-scale irrigation systems, and the remainder to Lake Chapala and for domestic and industrial uses. Of the 9 irrigation districts, ARLID is the largest, taking approximately 44 percent (or 880 MCM) of all the water stored for use within the districts (CNA 1992).

There are roughly 24,000 water users in the irrigation district, with 55 percent classified as *ejidatarios;*[3] and 45 percent classified as small private growers.[4] The average landholding in the irrigation district is 5 hectares.

The climate has been classified as moderate subhumid with a mean yearly precipitation of 750 mm and a mean temperature of 19 ^{0}C. Mean yearly evaporation is approximately 2,000 mm, and the mean relative humidity is about 60 percent. The dry winter season, with approximately 80 mm of rainfall, starts in November and ends at the end of April. Rainfall in the summer, from May until November, is approximately 670 mm.

Surface water for the district is provided by four earthen dams with a com-

[3]Members of the land reform communities that were created during the Mexican revolution in the early part of the twentieth century. Until the revision of Article 27 of the Constitution in 1992, *ejido* (land reform communities) land belonged to the Mexican State.

[4]The concept "small private grower" (*pequeño propietario*) is a misnomer because in Mexico such user category could allow ownership up to 100 hectares for an individual owner. In practice, this area becomes larger when a user divides the area among relatives.

bined storage capacity of 2,140 MCM, serving 77,697 hectares. In addition, there are 1,714 deep wells serving 35,075 hectares. The irrigation network comprises 475 km of main canals and 1,658 km of secondary and tertiary canals. Likewise, there is a network of approximately 1,031 km of drainage canals. Wheat and barley are normally grown during the dry winter season while sorghum, maize, and bean are the main crops grown in the wetter summer season. Farmers with access to groundwater tend to grow more vegetables.

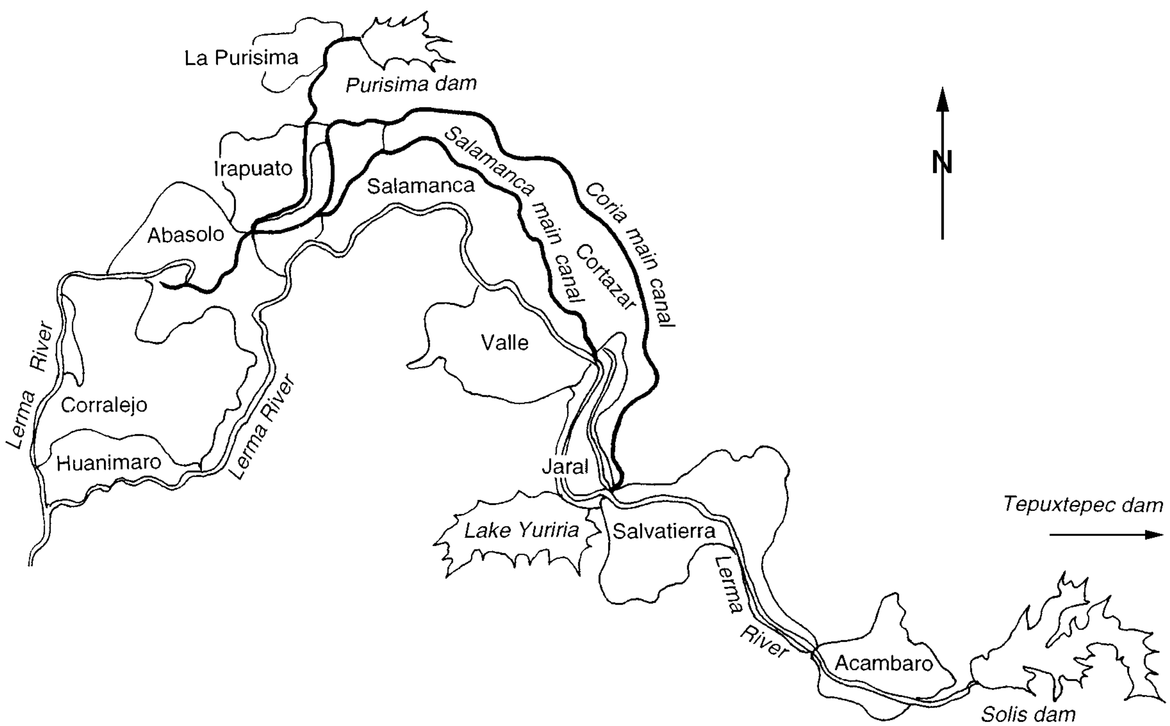
The State of Guanajuato has a high concentration of wells. Approximately 20 percent of all the wells in Mexico are found in this State. The State has 18 different aquifers 3 of which are exploited by the farmers of ARLID. The total area underlaid by these three aquifers is 330,600 hectares, with an average annual recharge of 500 MCM.

The irrigation district is subdivided into 11 units, referred to as modules. Each module is managed by an individual Water User Association (WUA). The irrigation district and the location of its eleven modules are shown in figure 1.

Cortazar Module

The Cortazar module is located at the center of the district and has a total command area of 18,694 hectares, including 7,760 hectares served by wells. It draws surface water supplies from the Coria main canal that conveys water from the Solis reservoir and the *Toro de Lomo* headwork on the Lerma River. The main canal runs along the east edge of the module for 72.2 km and irrigates 10,934 hectares on the left bank between the canal and the Salamanca main canal. The module

FIGURE 1.
The Alto Rio Lerma Irrigation District and its 11 modules.



is long and thin and is served by 54 secondary canals with a total length of 222 km. The drainage network extends to 95 km. Groundwater is extracted through 340 deep tube wells, supplying 5,796 hectares from wells installed by private owners and 1,964 hectares supplied from public wells managed by the module. Normally, areas irrigated by canals are different from those irrigated by wells, but some farmers use both irrigation sources. Although areas have been assigned to most public deep wells, often farmers have to make use of the canal infrastructure to be able to transport groundwater to their fields, which complicates the management of surface water. *Ejidatarios* (members of the ejidos) utilize 52 percent of the land area, under 32 ejidos with 1,962 users; 1,028 small private growers farm the remaining 48 percent of the land.

Salvatierra Module

The Salvatierra module is located upstream of Cortazar in the southern upstream part of the district, with a total command area of 16,093 hectares and 6,054 users. It draws water from two reservoirs, Tepuxtepec and Solis (figure 1) through six canal intakes on the Lerma River. The canal network is 251 km long. The total length of the drainage channels in the module is 208 km. There are 21 public wells and 170 private wells, irrigating 565 hectares and 2,753 hectares, respectively.

Approximately 85 percent of the land is farmed by ejidatarios with average landholdings of 2.7 hectares grouped in 44 ejidos. The balance is farmed by 972 small private growers with average holdings of 2.4 hectares.

Irrigation Management in ARLID

Institutional

Late in the 1980s, the Government of Mexico decided to restructure and modernize its agriculture sector. One component of the strategy adopted was an irrigation management transfer (IMT) program aimed at transferring management authority of the public irrigation systems from Comisión Nacional del Agua (CNA) to water user associations. As a result of this program, responsibility for O&M of the irrigation systems changed from being exclusively that of the federal government organization to be shared with the newly created WUAs. Officially, CNA's role is now restricted to the management of the nation's reservoirs, headworks, and main canals. Also in 1992, hydraulic committees were formed at the district level to make an annual irrigation plan, and to make sure that this plan is effectively implemented. These committees, where CNA, WUAs, and local state officials meet, provide a venue for participatory management, negotiation, and decision making.

Users began sharing responsibility for management with CNA in November 1992.[5] As a result of IMT, the WUA at Cortazar became responsible for O&M below the secondary canal offtakes on the main canal to the field level, while at Salvatierra the WUA became responsible for O&M of the entire distribution system, from the inlet regulators of the six main canals to the field level. Both WUAs have recruited professional and technical staff for operation of the irrigation system, managed by

[5]See Kloezen, Gracés-Restrepo, and Johnson (1997) for a detailed discussion of the IMT program in ARLID, and its impact on, amongst others, water use, O&M financing, maintenance, and agricultural and economic productivity.

general managers appointed by the boards of the associations. The boards are elected by a free vote of the users, and each comprises a president, secretary, and treasurer, with elected substitutes for each position. The board, plus delegates from each ejido, and two delegates per municipality representing the small growers, constitute a general assembly which generally meets every month. In 1996, Cortazar and Salvatierra WUAs employed 23 and 38 technical staff, respectively, about half of whom were ditch tenders and half administrative and maintenance staff. Prior to management transfer, CNA employed 273 staff in 1992, of whom only 116 remained in 1996.

Water Rights

The IMT program was accompanied by the promulgation of the new National Water Act in 1992. This act clarifies water rights and enables trading of water. Regulations that support the act were passed in 1994. Under the act, each WUA within an irrigation district is granted a concession, which entitles them to a share of the water available for each season. These shares or concessions are proportional to areas with surface water rights in each module. Although concessions are granted for periods of up to 20 years, CNA retains broad discretionary power over the concessionaire's right to use water and to water transactions (sale or rental).

Under the 1992 National Water Act, concessions may be granted to individual water users. However, there appears to be a strong preference on the part of CNA to make concessions to WUAs (Rosegrant and Schleyer 1996). The idea is that WUAs develop internal rules and regulations to grant subsidiary water rights equally to their members. Yet, in the case of ARLID none of the WUAs have established these rules and regulations. Water sales and rental arrangements among farmers are common practices, with or without CNA approval.

Under the new act, water can be traded, for instance, between two WUAs. Water sales need the approval of CNA, as well as of the majority of the general assembly of the WUAs involved.

Financial

Prior to transfer of management responsibility, farmers paid water fees directly to CNA. However, largely due to deteriorating infrastructure and maintenance services, the proportion of fees collected fell from 85 percent in the early 1960s to about 15 percent by the late 1980s (Palacios 1994a; Whiteford and Bernal 1996). Following the transfer, fees are set, and collected directly by the WUAs. Generally, farmers pay their fees prior to receiving their five irrigation services per year. In 1995 and 1996, irrigation service fees at ARLID were approximately US$7.5/ha/irrigation. With 5 irrigations per year, fees total US$37.50/ha, or $2.5/1,000 m^3 with an approximate total irrigation depth of 1,500 mm.

As a result of IMT, a negotiated proportion of the fees collected by the WUAs is paid to CNA for provision of O&M services at the headworks, and in the main canals. The proportion of fees paid to CNA ranges from 11 percent to 28 percent of the fees collected, depending on the complexity and level of service CNA provides to each module. CNA must approve the annual fee established by the WUA, and paid by the farmers.

Water Allocation, Distribution, and Scheduling Rules

Between modules. Allocation and distribution rules between the 11 modules with ARLID are based on three principles. First, at the beginning of each agricultural year (November) CNA determines the water availability in the reservoirs serving the district. Each module is concessioned a percentage of the available volume in the reservoirs. These concessions are in proportion to areas with surface water rights in each module, and are irrespective of the actual area irrigated, or the crops grown. Based on these concessions, and the water availability at the start of the agricultural year, the hydraulic committee makes the annual plan of how much volume will be allocated to each module. These planned volumes can differ slightly from the concessioned percentage, as every year, these volumes are adjusted for underusage or overusage of water by the module in the previous year.

Second, normally the full command area of each module can be irrigated. However, in times of water scarcity, the total area to be irrigated is determined by negotiation between CNA and the WUAs in the hydraulic committee. This can vary from module to module and is basically determined by physical characteristics of the module, experiences with past cropping patterns, and farmer's preferences.

Third, the hydraulic committee also decides on the number of irrigations that can be delivered to each module, the start and the end of each irrigation period, and whether irrigation will be provided during both winter and summer seasons. Generally, this decision counts for all modules. CNA is reluctant to open the dams to deliver water to only a few modules as this would mean considerable conveyance losses in the main system.

Within modules. Distribution rules within modules are based on four principles. First, a farmer cannot receive more irrigations than the maximum number of irrigation allocated to the module. Exceptions are made for farmers who grow crops like bean that require more frequent irrigations, but only if this extra irrigation falls within an irrigation period determined by the third allocation rule mentioned above. Second, each farmer can grow any crop he or she wants to grow. Third, farmers cannot request water for more than the area registered in their names. In case the hydraulic committee decides that less than the full command of the module can be irrigated, the WUA decides on the maximum area that can be irrigated by a farmer. Finally, the maximum volume of water a farmer can receive is determined by the WUA, based on a theoretical or planned water depth per irrigation. Generally, the WUA does not distinguish between water requirements of different crops, but uses a flat depth across its farmers, irrespective of the crops they grow.

Scheduling. Based on the total number of irrigations requested, and the planned water depth, the WUA calculates the total volume of water requested for the week. The weekly requests are communicated to CNA for scheduling deliveries to the modules. Daily, CNA and module staffs check at the module intake whether requested volumes are actually delivered. Water distribution between the secondary canals or laterals within a module is based on the same arranged scheduling. For each canal the total volume requested is calculated, and gates are set accordingly. Unlike what is practiced at the head of the module, volumes that enter the secondary canals are not measured, but are estimated by ditch tenders based on their experiences.

Operational Targets and Monitoring

Explicit management targets do not exist for ARLID, but interviews with system managers and daily observations of irrigation management practices reveal that CNA and the modules are concerned about meeting the following six management targets:

- Modules get the seasonal volume of water they have been allocated at the start of the agricultural year.
- Modules do not irrigate an area that exceeds the planned area.
- Modules receive the weekly scheduled volume of water they have requested for at the start of each week.
- Farmers get the number of irrigations they are entitled to, have requested, and have paid for.
- Farmers get sufficient water to irrigate the area they are entitled to irrigate.
- O&M costs should be fully recovered from the farmers.

System managers of both CNA and the WUAs use several techniques to monitor whether these targets are met. Monitoring is done at field, module, and district levels.

At the field level, ditch tenders report daily to the WUA, how many farmers have received water, for how much area, and for which crop. At the end of each day, ditch tenders meet at the module office to check whether their reports correspond with the weekly schedule. An estimate of the volumes delivered to each farmer is also reported. These reports are aggregated for the entire module, and are sent to the CNA district office weekly.

At the module level, daily measurements are taken at the head of the main canal, as well as at a small number of other hydrological control points. Daily reports mention both planned and actual volumes, and they carry signatures of both CNA and the WUAs. A weekly report that totals daily volumes is sent to the CNA district office.

At the district level, CNA aggregates the reported volumes, irrigated areas, and crops, and produces monthly reports which are presented and discussed at the hydraulic committee meeting. Finally, as farmers have to pay prior to each irrigation they receive, WUAs are able to keep good track of the total amount of fees paid by farmers. At the end of each season, the WUAs report their total fee collection to CNA. As the seasonal plan defines the total area to be irrigated as well as the number of irrigations to be delivered, it is easy to calculate the total planned fee collection, and to monitor, whether actual collection follows planned collection.

Although the described activities should be sufficient to monitor daily, weekly, monthly, and seasonal performance relative to the six targets mentioned above, a few practices limit this. First, the ditch tenders' reports form the basis for most of the data reported to both the modules and the CNA district office, and the estimates are very often inaccurate and unreliable. Second, monitoring of daily and weekly water distribution is based on aggregated field reports, rather than on real measurements at the canal level (except for the head of the main canal). Even though all WUAs use computers, aggregation of field-level data takes much time. As a consequence, the production of weekly, monthly, and seasonal reports takes a long time, and these reports hardly serve as tools to take immediate decisions when needed.

Data Collection Methodology

The research described here has been carried out in collaboration with the staff of Cortazar, and Salvatierra WUAs, officials of the CNA district office in Celaya, and IWMI staff. IWMI's study of ARLID was started in October 1995, with the establishment of project offices in the Cortazar and Salvatierra modules. Data collected include primary sources in the two modules and secondary sources with respect to the files kept by the respective WUA and CNA at regional, state, and central levels. Furthermore, other organizations related to the agriculture sector were visited periodically to gather further information, and to cross-check data collected from the modules and CNA. Secondary data include yields, farm gate prices, area irrigated, cropping pattern, canal flows, pumped volumes, and climate at different system levels.

Several tools were applied to check the quality of secondary data. The aggregation of module-level data provided a cross-check for data collected at the district level. Secondary data were further cross-checked by data collected from other sources like rural development banks. Primary hydrologic data provided a tool to cross-check the quality of officially reported canal flows at different hydrologic control points in the system during a period of four irrigation seasons.

Primary field data collection activities included three components:

- daily field observations of practices related to water management by leaders of WUAs, CNA staff, ditch tenders, and farmers
- field measurements related to canal water flows, volumes pumped by wells, and energy consumption of wells
- a household survey to establish the cost of production and the cost of water to farmers

For each module a study sample area was selected. In Cortazar two laterals were monitored. Lateral "A" commands 650 hectares, while lateral "B" serves 352 hectares. Within each lateral, 20 users were selected who were at head, middle, and tail ends representing existing land tenure arrangements (ejido v. private) and the water source (canal v. well). In each one of the selected fields the volume delivered for each irrigation was measured. In addition, the cost of production as well as gross value of production were calculated for each of these fields. With respect to canal water measurement, 11 control points were selected, and calibrated. At these points, flow measurements were made twice a day during the winter and summer seasons. Wells were also calibrated and monitored daily. In figure 2A, a schematic representation of the research layout for the Cortazar module is provided.

For Salvatierra, the entire main canal, Gugorrones, commanding 1,200 hectares, and its six short laterals were selected. Flow measurements were made twice daily at four points in the main canal, and the headwork of each lateral. In addition, in two of the laterals, four additional points were monitored. Within these two laterals, 15 users were selected, and the same measurements were taken as in the case of the selected fields in Cortazar. Figure 2B shows the research layout in the case of the Salvatierra module. The FAO's CROPWAT, and its complement CLIMWAT software packages were utilized to calculate the crop water requirements (FAO 1996). The program is based on the calculation of potential evapotranspiration

FIGURE 2A.
Schematic representation of selected laterals and measurement points in the Cortazar module.

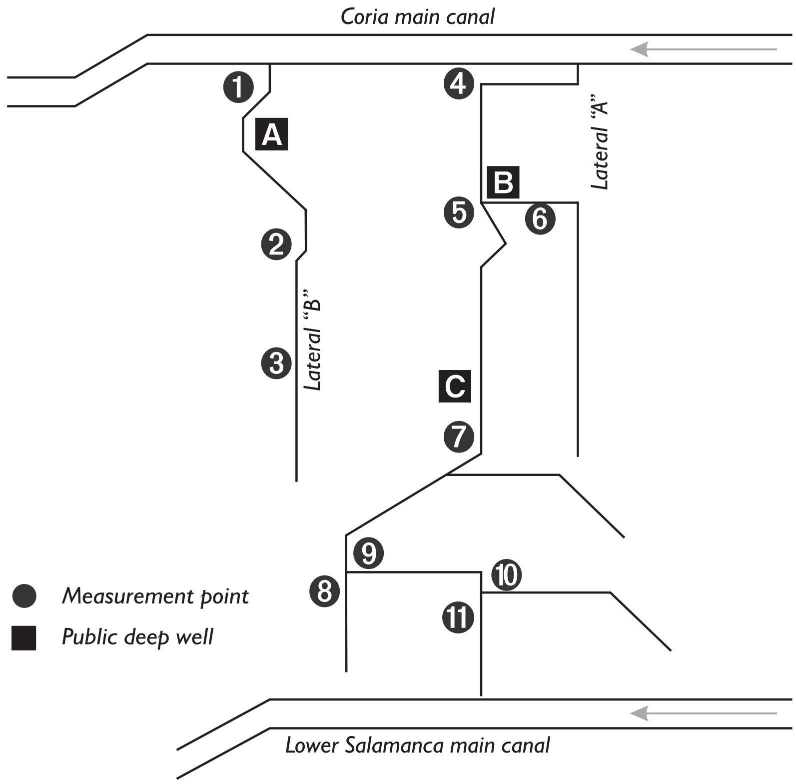


FIGURE 2B.
Schematic representation of measurement points in the Gugorrones main canal, in the Salvatierra module.

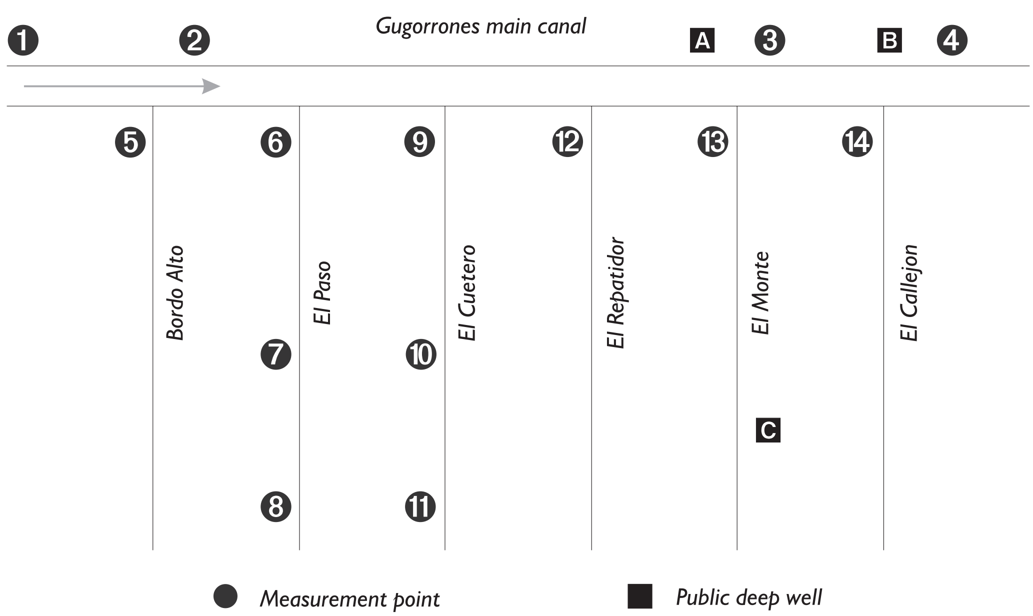


TABLE 1.
Performance indicators applied in this report.

Comparative Indicators	Alto Rio Lerma Irrigation District	Cortazar module	Salvatierra module	Selected canals	Selected fields
Relative water supply (ratio)	✓	✓	✓	✓	✓
Relative irrigation supply (ratio)	✓	✓	✓	✗	✗
Water delivery capacity (ratio)	✓	✓	✓	✗	✗
Production per cropped area ($/ha)	✓	✓	✓	✗	✓
Production per unit command ($/ha)	✓	✓	✓	✗	✗
Production per unit irrigation supply ($/m^3)	✓	✓	✓	✗	✗
Production per unit water consumed ($/m^3)	✓	✓	✓	✗	✗
Gross return on investment (%)	✓	✓	✓	✗	✗
Financial self-sufficiency (%)	✓	✓	✓	✗	✗
Fluctuation in static water tables (m/year)	✓	✗	✗	✗	✗
Area lost to waterlogging and salinity (%)	✓	✓	✓	✗	✗
Internal Indicators					
Actual supply over planned supply (%)	✓	✓	✓	✓	✓
Actual supply over concessioned supply (%)	✓	✓	✓	✗	✗
Actual supply over reported supply (%)	✗	✗	✗	✓	✓
Actual RWS over planned RWS (%)	✓	✓	✓	✗	✓
Actual RWS over reported RWS (%)	✓	✓	✓	✗	✓
Spatial distribution of RWS (ratio)	✗	✗	✗	✓	✗

✓ = applied ✗ = not applied

(ETo) through the modified Penman-Montieth equation, and provides three methods for the calculation of effective rainfall. Data on humidity, windspeed and hours of sunshine were taken from two nearby stations given in CLIMWAT. Rainfall as well as the maximum and minimum temperature data were collected from five stations within or near the district, and from the two selected modules.

The data collection procedures described above are evaluated later in this report, after the discussion of the result. A list of indicators used in this report is presented in table 1 that distinguishes between IWMI's minimum set of comparative indicators, and a small number of process indicators that were added. Generally, comparative indicators are only measured at higher system levels, such as modules or the entire district. Definitions of the comparative indicators are given in the annex, as well as in Molden et al. (1998).

The selected process indicators shown in table 1, basically follow the management targets mentioned earlier in this report. They were calculated at the district and module levels. The basis of internal monitoring of operational performance comprises the data collected by the ditch tenders at the field level. Several process indicators were also applied for selected secondary canals, and fields.

The basic data set used to obtain the process indicators at the district level, and the two modules are presented in table 2. Data on canal water and public wells are considered as one unit as they are often reported together, whereas private wells operate and are reported separately. As can be seen from this table, this report does not provide temporal comparisons as these are discussed in detail, in Kloezen, Garcés-Restrepo, and Johnson (1997).

Production values in table 2 are already given in 'equivalent' yields so as to follow the standardized procedure defined in the annex. For the winter season, wheat was chosen as the 'equivalent' crop; for summer, sorghum. The table includes the two main climatic parameters, rainfall and evaporation, although others have been utilized in the calculations of the crop water requirements. Finally, corresponding farm gate and world market prices of base crops are given to calculate the agriculture-based indicators.

TABLE 2.
Basic data set for ARLID and the Cortazar and Salvatierra modules, in winter 1995–96 and summer 1996.

	Alto Rio Lerma Irrigation District	Cortazar module	Salvatierra module
Gross command area (ha)			
Surface irrigation	77,697	10,934	12,775
Public wells	7,421	1,964	565
Surface irrigation plus public wells	85,118	12,898	13,340
Private wells	27,654	5,796	2,753
Cropping Intensity (%)			
Surface and public wells			
Winter 1995-96	70	81	50
Summer 1996	60	71	54
Private wells			
Winter 1995-96	75	89	23
Summer 1996	90	83	130
Main Crop (% of total cropped)			
Surface and public wells			
Winter 1995-96	Wheat (92%)	Wheat (94%)	Wheat (68%)
Summer 1996	Sorghum (81%)	Sorghum (90%	Maiz (39%)
Private wells			
Winter 1995-96	Wheat (62%)	Wheat (54%)	Wheat (70%)
Summer 1996	Sorghum (82%)	Sorghum (74%)	Maiz (53%)
Production (tons/ha)			
Surface and public wells			
Wheat equivalent, winter 1995-96	6.7	7.4	6.6
Sorghum equivalent, summer 1996	9.8	8.8	11.9
Private wells			
Wheat equivalent, winter 1995-96	8.9	11.1	7.2
Sorghum equivalent, summer 1996	9.6	10.7	9.6

Continued

TABLE 2. *(Continued)*

	Alto Rio Lerma Irrigation District	Cortazar module	Salvatierra module
	Gross Irrigation Supply (x 1,000 m^3)		
Surface			
Winter 1995-96	667,440	106,123	123,651
Summer 1996	139,236	26,743	22,227
Private wells			
Winter 1995-96	191,370	42,156	5,182
Summer 1996	111,002	22,584	24,624
	Rainfall (mm)		
Total, winter 1994-95	54	53	51
Effective, winter 1994-95	44	42	41
Total, summer 1995	683	724	670
Effective, summer 1995	510	523	506
	Evaporation (mm)		
Winter 1995-96	929	1,068	822
Summer 1996	1,098	1,262	893
	CROPWAT Water Requirement (mm)		
Surface and public wells			
Winter 1995-96	500	511	428
Summer 1996	497	546	501
Private wells			
Winter 1995-96	467	411	412
Summer 1996	507	536	526
	Sales Prices (US$ / mt)		
Farm gate price, wheat winter 1995-96	247	245	247
Farm gate price, sorghum summer 1996	120	120	120
World market price, wheat winter 1995-96	262	262	262
World market, sorghum summer 1996	105	105	105

Note: The overlap of winter and summer cropping in Salvatierra, explains why the reported actual irrigated area under wells for the summer season exceeds the gross command area.

Water Use Performance

Comparative Performance Indicators

Relative water supply (RWS). This indicator is the ratio of total water supply to the total demand at field level, and can be used both as a measurement of adequacy (Levine 1982) and seasonal timeliness (Meinzen-Dick 1995). According to IWMI's definition (the annex), the total crop demand at field level includes consumptive use, non-beneficial ET, losses to drains, and net flow to groundwater. Due to lack of reliable data, and the complexity of the surface-groundwater interface, non-beneficial ET, losses to drains, and flows to groundwater could not be measured, but are estimated to be 5 percent of total demand.

The conclusion that can be derived from table 3 is that the RWS values are high, generally above 2.0 at the module (actual supply) level. Previous worldwide experience with the RWS indicator would suggest that neither the district nor the modules faced a constraining water availability situation during the periods observed, and that water distribution is not tightly related to crop water demand (Levine 1982; Murray-Rust 1983; and Garcés 1983). In all cases, seasons, and water sources, the water supply has adequately met the crop water requirements.

RWS values for private wells are generally lower than those for canal water in the winter season, but high for the summer season. However, given that the RWS values for canals are calculated at their offtake points, while those for the private wells represent on-farm level water supply, it is concluded that the farmers who use wells use more water. Two reasons explain this. First, private well owners generally do not wait for the rains to come but start irrigating as soon as they can. As a result of the late rainfall onset during the summer of 1996, private well owners had already com-

TABLE 3.
Water-based comparative indicators, in the Alto Rio Lerma Irrigation District, and the Cortazar and Salvatierra modules, in winter 1995–96 and summer 1996 (ratio).

Surface irrigation and public wells	Season	Type	Alto Rio Lerma Irrigation District	Cortazar module	Salvatierra module
Relative water supply	Winter 1995–96	Actual	2.4	2.1	4.4
	Summer 1996	Actual	1.9	1.9	2.0
Relative irrigation supply	Winter 1995–96	Actual	2.5	2.2	4.8
	Summer 1996	Actual	0.0	12.9	0.0
Water delivery capacity	Winter 1995–96		4.6	1.1	2.2
	Summer 1996		5.6	1.3	2.6
Private wells					
Relative water supply	Winter 1995–96	Actual	2.1	2.1	2.1
	Summer 1996	Actual	2.2	2.2	2.3
Relative irrigation supply	Winter 1995–96	Actual	2.2	2.2	2.2
Summer 1996		Actual	0.0	26.4	16.7

pleted one irrigation, which explains the slightly higher actual RWS summer values for wells as compared to surface water. Second, owing to subsidized energy tariffs the cost of pumping water has not yet exceeded the cost of surface water (see tables 3 and 9) and as such, has never been an incentive for well owners to economize on water.

Some of the excess pumped water is expected to percolate to the aquifers and hence can be reused. However, in places within the district the aquifers are located 150 meters below field level, which makes measuring recharge from excess irrigation very complicated. As a result, reliable CNA data on this type of recharge do not exist.

The water-related comparative indicators for the entire district and the two selected modules are summarized in table 3 by source, season, type, and district and module levels. The actual relative water supply (RWS), based on actual flow measurements at the intakes of the modules, provides the comparative indicator.

Relative irrigation supply (RIS). This indicator is the ratio of irrigation supply to irrigation demand (total demand less effective rainfall). Effective rainfall is assumed to be 80 percent of total rainfall. This 80 percent method is one of the three methods suggested by CROPWAT, and is supposed to be suitable for areas with relatively low storms. Storms in ARLID never exceed 20 mm / day. By definition, effective rainfall can never exceed the crop water requirements. In cases where effective rainfall equals crop water requirements, the RIS value is zero.

Looking at the winter season values in table 3, we again find values above 2 for both canal and well water suggesting relatively abundant irrigation supplies. For the rainy summer season the values for both water sources are either very high (high effective rainfall and hence low irrigation demand) or zero (effective rainfall equals crop water requirement). In the case of the summer values for Cortazar, an increase of 50 mm in the effective rainfall, obtained by shifting from the 80 percent method to the US Bureau of Reclamation method, would have resulted in the RIS value as zero.

Water delivery capacity (WDC): This nondimensional indicator addresses the question of whether the system has been designed and constructed in such a way as to be able to meet the peak water demand in a particular period. From table 3, it can be seen that both the Coria main canal in Cortazar and the Gugorrones main canal in Salvatierra have sufficient capacity at their intakes[6] and therefore account for the high RWS values. The high values for the system as a whole can be explained because the river itself carries the discharges supplied by the dams to the various main canals.

Process Performance Indicators

Actual supply over concessioned supply. In November 1995, the start of the 1995–96 agricultural year, the gross storage in the four reservoirs supplying the district was 1,118 MCM, of which approximately 742 MCM were assigned to irrigation. This gross storage is the sixth lowest level in a series of 14 years as reported in Kloezen, Garcés-Restrepo, and Johnson (1997), while the volume assigned to irrigation is about 140 MCM less than the annual average of 880 MCM available for the district. The hydraulic committee decided that this volume was sufficient for a total of five irrigations: four for irrigation of winter wheat, and a single irrigation for summer sorghum.

Table 4 shows the distribution of the concessioned percentages, the total yearly planned volumes to be supplied to the

[6]It is important to note that the water delivery capacity of the Gugorrones Canal reduces rapidly from head to tail as a result of its very poor physical condition.

modules, and the actually supplied volumes during both the winter and the summer seasons. The average annual application was 1,500 mm; however, the recorded irrigation depths in the winter season show a marked variation between the modules. This variation is because the actual area to be irrigated and the crops grown are determined separately by each module. Those modules with higher apparent water depths opted to crop a reduced area.

Overall, the actual water volume supplied closely matched the concessioned and planned volumes, though actual deliveries exceeded the allocated volumes by some 5 percent. There is some evidence of variations in water allocations between modules (CV=10%). However, there is little evidence of tail-end problems typical of many systems. This good level of performance of water distribution between modules at the district level is consistent with the good performance of the other post-transfer years (Kloezen, Garcés-Restrepo, and Johnson 1997).

Actual supply over planned and reported supply. At the level of the selected canals and laterals in Cortazar and Salvatierra, actual water supplies were obtained by daily flow measurements. Figures 3A and 3B analyze the supplies for each lateral monitored in Cortazar. The cycles observed in the graphs correspond to individual irrigations provided by the WUA. Planned and reported values show a very high correlation. The reason for this is that, at the level of the laterals and fields, ditch tenders only estimate, and do not measure volumes. Although each delivery should provide a uniform, planned irrigation depth to each farmer who requested an irrigation, the ditch tender fixes the time allocated to irrigate one hectare. The duration of supply is determined by the ditch tender's experience and the relationship with the individual water

TABLE 4.
The distribution of concessioned, planned and actual volumes between the modules of the Alto Rio Lerma Irrigation District, agricultural year 1995–96.

		1	2	3	4	5	6	7	8	9
	Module	Water concession (% of total water)	Planned volume (x 1,000 m^3)	Actual volume supplied to irrigated area					Actual / Planned %	Actual/Concessioned %
				Winter mm	Summer mm	Total mm	Total (x 1,000 m^3)	As % of total actual supply		
Head	Acambaro	8	67,808	1895	168	2063	62,886	8	93	97
	Salvatierra	16	125,735	1846	310	2156	145,878	19	116	115
	Jaral	6	43,250	1239	267	1506	49,715	6	115	103
	Valle	13	99,216	865	259	1124	90,057	12	91	91
Middle	Cortazar	17	133,271	1013	291	1304	132,866	17	100	98
	Salamanca	15	90,105	794	212	1006	95,209	12	106	82
	Irapuato	6	44,834	1065	282	1347	47,072	6	105	103
	Abasolo and Corralejo*	14	111,222				118,295	15	106	108
Tail	Huanimaro *	4	26,392				30,530	4	116	107
	Total	100	741,833				772,508	100		
	Average			1,245	256	1501			105	101
	Coefficient of variation			451	49	446			9	10

*Separate data on water depths for Abasolo, Corralejo, and Huanimaro are not available.

users. Ditch tenders only roughly report the time farmers receive water. The ditch tender's main concern is to report the area a farmer had requested and paid an irrigation for, rather than the actual volume supplied. Using the planned water depth, they calculate the theoretical discharge (m^3/s), as recorded in their daily irrigation reports to the WUAs.

The actual values are almost consistently higher when compared to the planned values. This can be explained through a combination of poor control at the intakes of the laterals, and failure to adjust gate settings after the conditions of the infrastructure had changed as a result of intra-season maintenance, as was the case in week 7 of lateral A (figure 3A).

Figure 3C shows the weekly supplies for the selected main canal in the Salvatierra module. Unlike the examples from Cortazar, this case shows more consistency between the measured and planned values, suggesting better water control at the intake point. The large difference between reported and measured values is because the ditch tenders calculate the former at the field level, and therefore have not included the conveyance losses in the main canal.

With respect to the water demand, table 5 compares the planned water requirements for the winter season of both modules with the theoretical crop water requirements obtained through CROPWAT.

The requirements planned by the modules incorporate the perceived canal losses at each level of the system. For Cortazar, the ratio of the CROPWAT to the field-level values corresponds to the planned application efficiency, in this case, 70 percent. The ratio between field and secondary canal values constitutes the distribution efficiency planned by the module, in this case, 85 percent. Finally, the ratio between secondary and main canal values corresponds to the planned conveyance efficiency, in this case 80 percent. Thus, the system's planned efficiency of 48 percent can be considered typical of a canal system like ARLID.

FIGURE 3A.
Planned, actual, and reported volumes of lateral A of the Cortazar module, in winter and summer seasons, 1995–96.

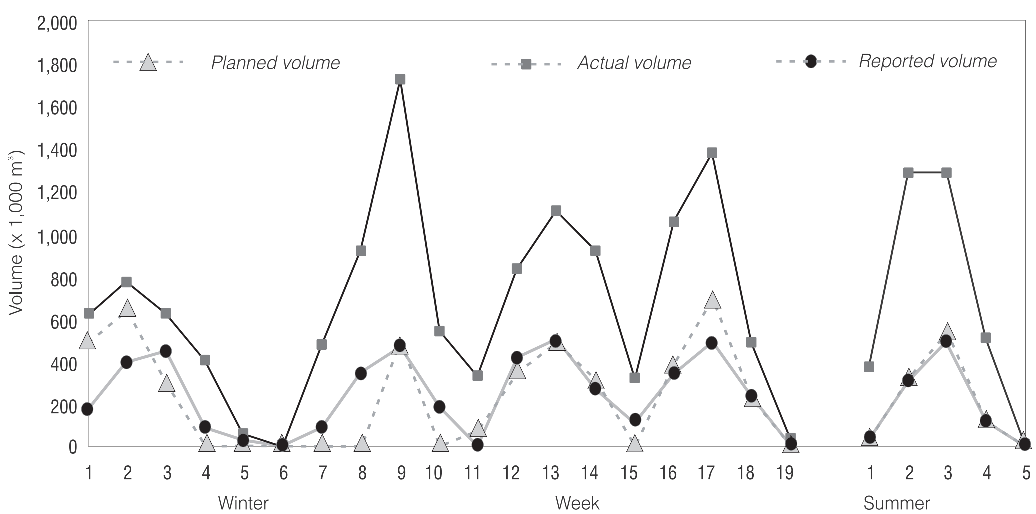


FIGURE 3B.
Planned, actual, and reported volumes of lateral B of the Cortazar module, in winter and summer seasons, 1995–96.

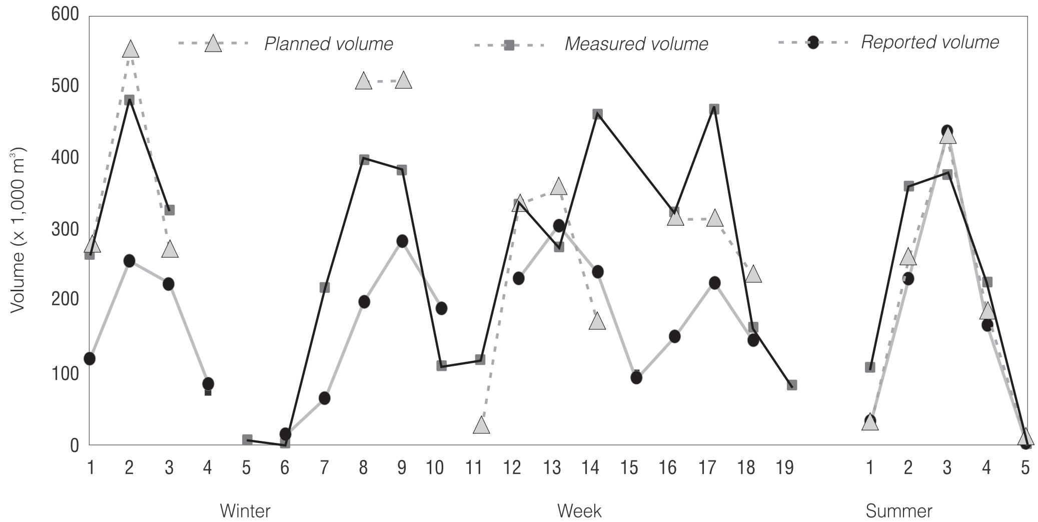


FIGURE 3C.
Planned, actual, and reported volumes of the Gugorrones main canal, in the Salvatierra module, in winter and summer seasons, 1995–96.

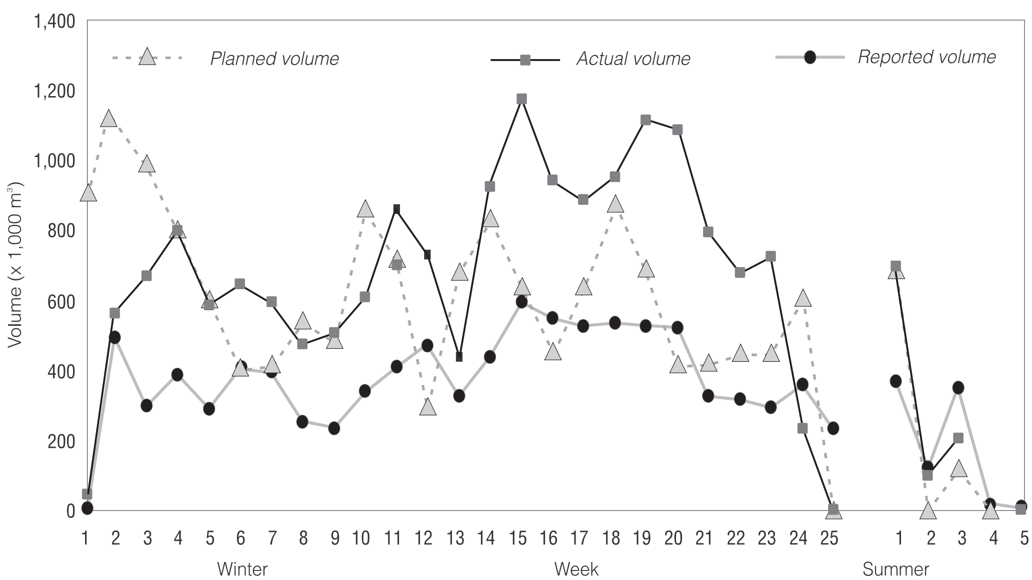


TABLE 5.
Calculated (CROPWAT) and planned water requirements in the Cortazar and Salvatierra modules, in winter 1995–96 (mm/season).

Crop	CROPWAT requirements (mm)	Planned requirements by the module (mm/season)		
		Field	Secondary canal	Main canal
Cortazar module				
Aconchi wheat	607	775	930	1,175
Salamanca wheat	523	775	930	1,175
Onion	477	775	930	1,175
Barley	466	775	930	1,175
Tomato	493	775	930	1,175
Vegetables	310	775	930	1,175
Salvatierra module		Field		Main canal
Aconchi wheat	580	850		1350
Salamanca wheat	505	850		1350
Tomato	508	850		1350
Onion	477	850		1350
Chili	470	850		1350
Chickpea	460	850		1350
Barley	409	850		1350
Bean	303	850		1350
Vegetables	280	850		1350

Because of the irrigation network configuration of the Salvatierra module there are really no secondary canals as such, and therefore those values are omitted in the table; but the rationale for efficiencies is the same. Two reasons explain the difference in the theoretical crop water requirements between Cortazar and Salvatierra: the difference in evaporation (table 2) as a result of altitude and humidity differences, and the considerable difference in planting dates. An important observation from table 5 is that neither module differentiates on crop water requirements for different crops. Irrigation scheduling and planning are based on the main crop, in this case, wheat. This practice results in excess calculation of irrigation requirements, especially in Salvatierra with its diversified cropping pattern, which comprises 68 percent wheat, 22 percent bean, and 10 percent vegetables.

Actual RWS over planned and reported RWS. To calculate process indicators related to RWS, three different RWS values are measured, using different supplies in the numerator of the indicator (table 6). *Actual RWS*, is calculated using actual water supplies obtained from flow measurements by CNA and the WUAs at the intakes of all modules; p*lanned RWS*, using planned water supplies obtained from administrative records from both CNA and the WUAs; and r*eported RWS*, using recorded volumes by ditch tenders. In the case of the private wells, two different RWS values are calculated: actual RWS, using actual pumped volumes; and reported RWS, using pumped volumes as recorded by ditch tenders.

An important conclusion from table 6 is that, in Salvatierra, actual and planned values match relatively well. Actual values are only slightly higher than reported values.

TABLE 6.
Actual over planned and reported RWS values in the Alto Rio Lerma Irrigation District and the Cortazar and Salvatierra modules, in winter 1995–96, and summer 1996.

Source	Season	RWS type (ratio)	Alto Rio Lerma Irrigation District	Cortazar module	Salvatierra module	Alto Rio Lerma Irrigation District		Cortazar module	Salvatierra module
Surface irrigation and public wells	Winter 1995-96	Actual	2.4	2.1	4.4				
		Planned	2.5	2.4	3.3	Actual / Planned	96%	87%	133%
		Reported	1.6	1.5	2.0	Actual / Reported	151%	137%	218%
	Summer 1996	Actual	1.9	1.9	2.0				
		Planned	2.1	2.0	2.1	Actual / Planned	90%	92%	93%
		Reported	2.0	1.8	2.3	Actual / Reported	98%	105%	84%
Private wells	Winter 1995-96	Actual	2.1	2.1	2.1				
		Reported	1.8	2.0	not reported	Actual / Reported	118%	107%	
	Summer 1996	Actual	2.2	2.2	2.3				
		Reported	1.3	2.2	not reported	Actual / Reported	172%	100%	

This suggests that the management succeeds in closely following the irrigation plan. Salvatierra has higher water supplies per unit of land as a result of the relatively low cropping intensity: 50 percent for the inter-season, compared to 81 percent for Cortazar, and 70 percent for the entire district. Furthermore, the diversified cropping pattern in Salvatierra shows that supply and demand are less well-matched (Kloezen, Ramirez, and Melgarejo 1996). Because of its higher number of farmers and a high degree of land fragmentation, ditch tenders of the Salvatierra module have many problems in obtaining adequate information on the crops farmers actually grow, causing severe problems with seasonal and weekly irrigation scheduling. The table also shows that during the winter season, actual RWS value is much higher than the reported value. Part of the reason for this is that actual values are measured at the intake of the module and reported values estimated at the field level. In addition, ditch tenders have a tendency to underreport actual irrigation supplies.

This observation is supported by the data obtained from IWMI's measurements at the field level. Actual, planned, and reported RWS values of selected fields in the two modules were calculated and are reported in table 7A. In the case of Cortazar, the values show little variation between the different fields observed, and are in line with those obtained for higher levels of the system. For Salvatierra, the values are consistently higher than in Cortazar, and with somewhat more variation, corroborating higher water availability. The last three columns of the table relate the differences that arise from the different RWS methods and again highlight the high correlation between planned and reported values.

Table 7B provides the same information for the summer season, for Cortazar alone. For the same reason as explained above, the summer season values show a high difference between fields irrigated with surface water and those irrigated with wells: an average of 1.8 for the former and 2.4 for the latter. For Salvatierra, only actual values are available. The average value of the actual RWS of fields irrigated by canals is 2.3, while the average value for fields irrigated by wells is 2.4.

TABLE 7A.
Actual, planned, and reported relative water supplies in seleted fields, Cortazar and Salvatierra Modules, winter 1995–96.

Cortazar field	Irrigation source	Actual water depth (mm)	Reported water depth (mm)	1 RWS-Act	2 RWS-Plan	3 RWS-Rep	4 1/2 (%)	5 1/3 (%)	6 2/3 (%)
1	Surface	834	728	1.7	1.6	1.5	106	113	107
2	Surface	832	794	1.7	1.6	1.6	106	106	100
3	Surface	898	803	1.6	1.4	1.4	114	114	100
4	Surface	961	813	1.9	1.6	1.7	119	112	94
5	Surface	825	760	1.7	1.6	1.6	106	106	100
6	Surface	844	801	1.7	1.6	1.6	106	106	100
7	Surface	931	797	1.9	1.6	1.6	119	119	100
8	Surface	1,122	781	2.2	1.6	1.6	138	138	100
9	Surface	1,040	181	1.5	1.4	1.4	107	107	100
10	Surface	1,057	828	1.6	1.4	1.5	114	107	93
11	Surface	1,177	795	2.3	1.6	1.6	144	144	100
12	Public well	994	762	2.0	1.6	1.6	125	125	100
13	Private well	958	–	1.7	1.4	–	121		
14	Private well	861	–	1.5	1.4	–	107		
15	Private well	971	–	2.0	1.6	–	125		
Average	954	737	1.8	1.5	1.6	117	116	100	
Salvatierra field	Irrigation source	Actual water depth (mm)	Reported water depth (mm)	1 RWS-Act	2 RWS-Plan	3 RWS-Rep	4 1/2 (%)	5 1/3 (%)	6 2/3 (%)
1	Private well	1,151	–	2.1	1.6	–	131		
2	Private well	1,007	–	2.0	1.7	–	118		
3	Surface	843	915	1.7	1.7	1.8	100	94	94
4	Private well	1,110	0	2.2	1.7	–	129		
5	Surface	732	846	3.1	3.5	3.5	89	89	100
6	Surface	1,173	1,296	2.3	1.7	2.6	135	88	65
7	Surface	858	0	2.3	2.3	0	100		
Average		982	611	2.2	2.0	2.0	108	90	87

Spatial distribution of RWS. The RWS values for different canal reaches within both areas of study are shown in figures 4A and 4B. In Cortazar, the tail end of lateral B received more water during the winter season than the head, or the middle. As is demonstrated in figure 3B, actual water delivery to this lateral always exceeded planned deliveries. Because of the good condition of the lateral, head- and middle-end farmers never have difficulties with taking water into their field. As a consequence, excess water is carried to the tail end, which explains the high RWS value. Lateral A is much longer and suffers from physical problems, inducing the typical head-tail difference. The high value of 6.9 is justified since the reach runs along the river in very coarse ground, and canal losses are very high (Kloezen, Garcés-Restrepo, and Marmolejo 1996). The values for the summer follow the same pattern as before. Also, unlike the head-end area, which is dominated by large landholdings of private growers, control of water distribution in the tail end is difficult because of the large number of small fields that are cultivated by the ejidatarios. In general, summer RWS values are much lower, and show more spatial uni-

TABLE 7B.
Actual, planned, and reported RWS values in selected fields in the Cortazar module, in summer 1996.

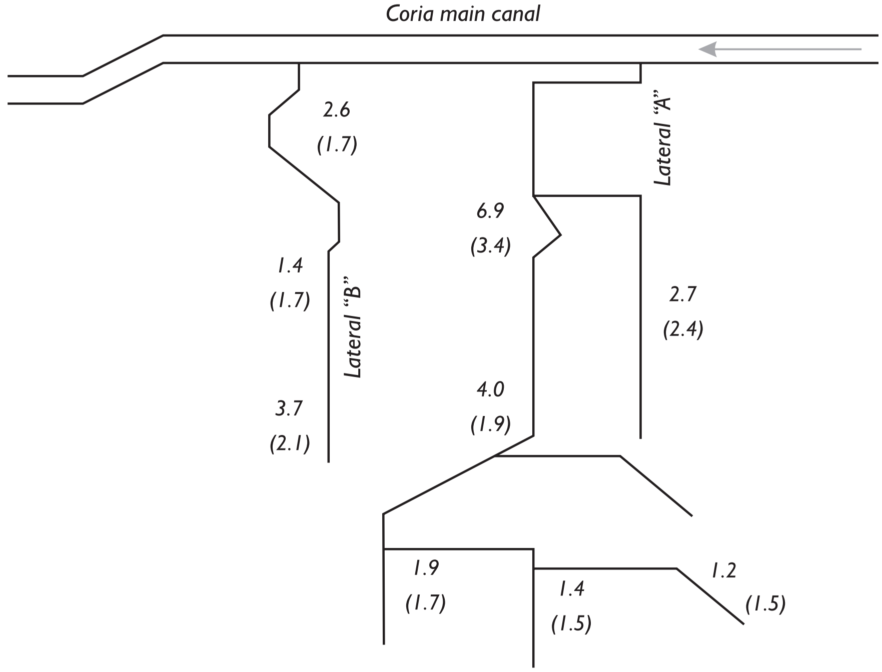
Field	Irrigation source	Actual depth (mm)	Reported depth (mm)	1 RWS-Act	2 RWS-Plan	3 RWS-Rep	4 1/2 (%)	5 1/3 (%)	6 2/3 (%)
1	Surface	274	0	1.9	1.8	1.3	102	138	135
2	Surface	225	196	1.8	1.8	1.7	97	103	106
3	Surface	269	232	1.8	1.8	1.8	102	104	102
4	Surface	491	253	2.3	1.8	1.8	125	124	100
5	Surface	210	228	1.7	1.8	1.8	96	98	102
6	Surface	260	231	1.8	1.8	1.8	101	103	102
7	Surface	208	229	1.7	1.8	1.8	96	98	102
8	Surface	253	229	1.8	1.8	1.8	100	103	102
9	Surface	253	231	1.8	1.8	1.8	100	102	102
Average	Surface	271	203	1.8	1.8	1.7	102	108	106
10	Well	599	204	2.5	1.8	1.7	136	143	105
11	Well	438	216	2.2	1.8	1.7	119	124	104
12	Well	595	207	2.4	1.8	1.7	135	142	105
13	Well	620	289	2.5	1.8	1.9	138	133	96
14	Well	757	216	2.7	1.8	1.7	152	158	104
15	Well	719	248	2.7	1.8	1.8	148	148	100
16	Well	633	215	2.5	1.8	1.7	139	145	104
17	Well	628	216	2.5	1.8	1.7	139	144	104
18	Well	456	216	2.2	1.8	1.7	121	126	104
19	Well	693	278	2.6	1.8	1.9	145	141	97
20	Well	690	216	2.0	1.4	1.4	145	150	104
Average	Wells	621	229	2.4	1.8	1.7	138	141	102
Overall average		454	214	2.2	1.8	1.7	121	125	104

formity as all farmers get equal rainfall and only one irrigation is supplied.

Figure 4B shows the RWS pattern for the research site in the Salvatierra module. Water control in the Gugorrones main canal and its laterals is difficult because of the severe disrepair of the infrastructure, the large number of farmers, and the relatively small plots. Three public deep wells pump directly in the canal network, which further complicates water management. Furthermore, daily observations and measurements at the control points, selected wells, and fields show that many private well owners also illicitly irrigate with canal water. These factors explain why there is no uniform distribution of RWS values along the selected canal and laterals.

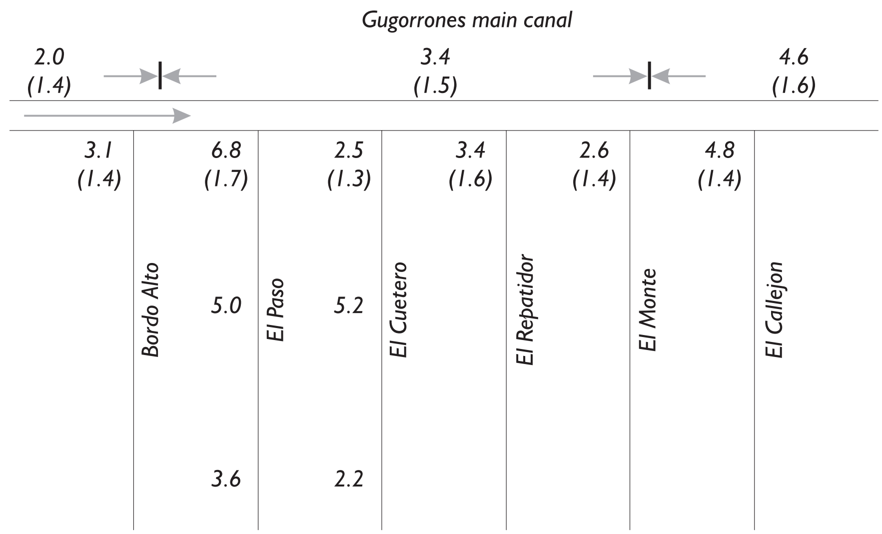
In addition to the factors explained above for each specific research site, three general explanations can be given as to why there is no typical head- tail-end distribution of RWS values. First, with RWS values generally above 1.5 at any of the system levels observed, guaranteeing access to water is not a major problem to farmers. Second, in an arranged schedule controlled system like ARLID, where farmers pay for each irrigation service that is provided, they make sure that they get the water they have requested and paid for, by making ditch tenders accountable for the way they distribute the water. Given the high levels of water availability, ditch tenders can easily meet these requests without having to control the system in a very strict way. Third,

FIGURE 4A.
Spatial distribution of RWS in two selected laterals in Cortazar module.



Note: Values within parentheses are RWS values, summer season, 1996 while the rest are WRS values, winter season, 1995–96.

FIGURE 4B.
Spatial distribution of RWS values in the Gugorrones main canal and its laterals, in the Salvatierra module.



Note: Values within parentheses are RWS values, summer season, 1996 while the rest are WRS values, winter season, 1995–96.

water distribution practices are generally defined by applying water to a fixed area, rather than by applying a fixed volume in a fixed time. As a result, generally farmers are provided with the volume they need to irrigate their crops.

Agricultural Performance

According to table 2, the winter wheat equivalent production in ARLID ranges from 6.6 tons / ha for canal irrigation in Salvatierra to 11.1 tons / ha for fields irrigated by wells in Cortazar. Unlike Salvatierra, many well owners in Cortazar grow high-value vegetables, which increase the wheat equivalent value. In contrast, Salvatierra has a very high summer sorghum equivalent production (11.9 tons / ha) as many farmers grow bean, which has a high wheat equivalent. Normally, the production of sorghum is approximately 9 tons / ha. These production values for wheat and sorghum are relatively high compared to other irrigation districts in Mexico (Palacios-Vélez 1994b), and nearby small-scale irrigation systems in the State of Guanajuato (Dayton-Johnson 1997). This report has not analyzed in detail the factors that explain these high values, but interviews with agronomists and farmers show that ARLID is favored by its fertile soils, good access to surface water and groundwater, and the availability of national and international providers of high quality inputs.

Table 8 summarizes the values of the comparative performance indicators that are related to agricultural output of the district and the two selected modules.

SGVP per unit of land cropped (US$/ton). The winter season values for canal water are close to US$1,800 / ha for both the district as a whole and the individual modules (table 8). Cortazar shows a slightly higher value due to the higher-value crops grown here under higher agricultural inputs. For the same period, the values for wells are consistently higher, which is a reflection of both better water control through wells and the higher-value crops usually grown under this technology. The corresponding summer season values follow a similar pattern, but the actual values are much lower as a result of depressed market values of the main crop, US$262 / ton for winter wheat against $105 / ton for summer sorghum. The diversified cropping pattern under surface irrigation in Salvatierra resulted in a relatively high SGVP for the summer crop.

The annual SGVP for each of the three units analyzed is approximately US$2,900 / ha cropped for surface irrigation, and ranges from $2,900 to $4,000 for wells. In comparison to 15 other systems studied by IWMI (Molden et al. 1998), the output per unit of cropped land of the modules in ARLID is among the highest, the reason being a relatively higher productivity (see table 2), rather than better prices for the staple crops, wheat and sorghum compared to, for instance, rice.

SGVP per unit of command area (US$/ton). The summer values for this indicator are much lower than those obtained fromthe previous indicator, the reason for which is already explained. The case for Salvatierra module is particularly relevant, given its low cropping intensity (table 2). The lower values are also influenced by the crop choice since the main crop for each season occupies much less area than for the district as a whole, or for the Cortazar module.

Comparison with other systems worldwide (Molden et al. 1998) again shows that the private well owners in the Cortazar module have a very high output. On the other hand, the output per unit command of all other farmers is much lower, with the output of the Salvatierra farmers (both surface and wells) being among the lowest of the systems studied. The most important factor that contributes to these low values in the Salvatierra module is the low crop intensity of the area under bean and vegetables.

SGVP per unit of irrigation supply (US\$/m^3). The values for the winter season under canal water show that the district (US\$0.16/m^3) and Cortazar (\$0.19/m^3) values exceed Salvatierra (\$0.09/m^3) by almost double. This is consistent with the latter's higher relative water supply (4.4), as could be seen from table 3. These values are consistent but slightly higher than those reported for the Coello (US\$0.12/m^3) and Saldaña (\$0.11/m^3) systems in Columbia, which are also arranged scheduled systems but under different climatic and economic conditions (Vermillion and Garcés-Restrepo 1996). Comparison with the 15 other systems reveals that irrespective of the relatively high RWS values found, the ARLID output per unit of irrigation supplied is in the range of medium to higher values for the winter season also. But from well water, the values are significantly higher in all cases.

TABLE 8.
Agriculture-based indicators in the Alto Rio Lerma Irrigation District, and the Cortazar and Salvatierra modules, winter 1995/96 and summer 1996.

	Season	Irrigation source	Alto Rio Lerma Irrigation District	Cortazar module	Salvatierra module
SGVP/Unit of land cropped US\$/ha	Winter	Surface	1,752	1,941	1,740
	Summer		1,028	921	1,253
	Entire year		2,780	2,862	2,993
	Winter	Private wells	2,320	2,912	1,887
	Summer		1,010	1,123	1,005
	Entire year		3,330	4,035	2,892
SGVP/Unit of command US\$/ha	Winter	Surface	1,228	1,576	874
	Summer		612	654	644
	Entire year		1,840	2,230	1,518\
	Winter	Private wells	1,730	2,579	431
	Summer		900	927	1,623
	Entire year		2,630	3,506	2,054
SGVP/Unit irrigation supply US\$/m^3	Winter	Surface	0.16	0.19	0.09
	Summer		0	0	0
	Winter	Private wells	0.25	0.36	0.23
	Summer		0.22	0.24	0.18
SGVP/Unit water consumed US\$/m^3	Winter	Surface	0.35	0.38	0.41
	Summer		0	0	0
	Winter	Private wells	0.50	0.71	0.46
	Summer		0.20	0.21	0.19

Although the market price for the main summer crop is much lower (US$105/ton) than for the winter season crop $262/ton) as could be seen from table 2, the values of production per unit of surface irrigation supplied are nonetheless higher since much less irrigation is needed due to the higher rainfall.

SGVP per unit of water consumed (US$/m^3). Generally, for the winter season, these values are higher than in the previous indicator because it excludes system losses and considers only that fraction of the water that was actually evapotranspirated by the crop, the non-beneficial ET, and losses to sinks and thus is no longer available to be used elsewhere. It should be noted that in the case of Salvatierra there is no longer a large difference with the district or the other module since the indicator is no longer influenced by the irrigation supply.

In addition to the standardized gross value of production, data on the cost of production of selected fields were collected and analyzed to enable to calculate the net income of production, as well as the cost of the water service to the farmer—be it through the irrigation service fee or the cost of pumping (table 9). The average net income is approximately 75 percent of the SGVP, but these percentages range from 70 percent for surface irrigation in both modules to 83 percent for well owners in Salvatierra.

The cost of water, related to wells includes both energy cost for pumping and

TABLE 9.
Average cost of irrigation tariff and pumping relative to total production costs and agricultural income of the selected fields in the Cortazar and Salvatierra modules, in winter 1995–96 and summer 1996.

Winter	Cropped area (ha)	Production cost (US$/ha)					SGVP and NVP (US$/ha)				Cost of water tariff o pumping as % of:		
Cortazar		Hired labor	Inputs	Machinery	Tariff or pumping	Total cost	Tons/ha	FG price/ton	SGVP	NVP	Total costs	SGVP	NVP
All (n=15)	4.9	40	295	161	33	530	7.2	253	1,821	1,290	6.3	1.8	2.6
Surface (n=11)	4.5	47	296	165	34	542	7.1	255	1,814	1,272	6.3	1.9	2.7
Wells (n=4)	5.8	22	294	151	31	499	7	248	1,838	1,339	6.3	1.7	2.3
Salvatierra													
All (n=6)	3.0	38	189	154	34	415	6.3	284	1,795	1,381	8.2	1.9	2.5
Surface (n=3)	2.3	47	188	146	35	415	4.1	330	1,341	926	8.4	2.6	3.8
Wells (n=3)	3.7	29	190	162	33	415	8.6	262	2,250	1,835	8.1	1.5	1.8
Summer													
Cortazar													
All (n=20)	5.0	24	204	75	37	340	9.1	133	1,210	871	10.8	3.0	4.2
Surface (n=8)	4.0	19	204	69	9	301	9.1	128	1,168	866	3.1	0.8	1.1
Wells (n=12)	5.8	28	204	79	55	365	9	137	1,230	865	15.1	4.5	6.4
Salvatiera													
All (n=13)	2.4	91	267	154	22	534	9.1	135	1,228	694	4.2	1.8	3.2
Surface (n=3)	2.3	70	256	99	9	435	6.2	149	923	488	2.1	1.0	1.9
Wells (n=10)	2.5	97	270	173	24	564	10.1	130	1,315	751	4.3	1.8	3.2

Notes: FG price = farm gate price; SGVP = Standardized gross value of production; NVP = Net value of production.

seasonal maintenance, but excludes capital costs. For Cortazar, the production costs offer no significant difference between water sources, with slightly lower values for wells. Likewise, productivity values of both gross and net income follow a similar trend with slightly higher values for wells. The final section of the table combines this information to show that the cost of the water service as a percentage of total cost of production is only 6.3 percent in all cases. Furthermore, the cost of water, related to income is even smaller, at less than 3 percent in all cases.

The situation for Salvatierra presents similar trends with somewhat higher variations between the two water sources. In terms of percentages, cost of the water service is around 8.2 percent, while it is less than 3 percent of the gross agricultural income.

Compared to the winter season, SGVP values for the summer season are much lower, especially for surface irrigated fields in Salvatierra. The average net income as a ratio of the SGVP ranges from 53 percent to 74 percent. Owing to problems with weeds, Salvatierra farmers have much higher expenses on hired labor and machinery. Similar to the winter season, the cost of water against total production cost is equally low in the summer season. The only exception is the cost of water for Cortazar farmers who use water from wells. This is explained by the fact that three of the farmers sampled, who used to irrigate with canal water during the winter season, decided to buy water from well owners for their summer crop. These farmers paid up to US$85/ha for their water, compared to an average energy cost of $18/ha (table 10).

TABLE 10.
Cost and energy use of selected private and public deep tube wells in the Cortazar and Salvatierra modules.

	Winter season 1995-96					Summer season 1996				
	Water use m^3/ha	Energy use m^3/Kwh	Energy cost US$/1,000 Kwh	Pumping cost US$/ha	Pumping cost US$/1,000 m^3	Water use m^3/ha	Energy use m^3/Kwh	Energy cost US$/1,000 Kwh	Pumping cost US$/ha	Pumping cost US$/1,000 m^3
Private wells Cortazar (n=10)	9,460	6.5	16.88	24.57	2.60	6,210	7.5	22.08	18.28	2.94
Public wells Cortazar (n=20)	6,160	6.0	16.88	17.33	2.81	11,460	7.0	22.08	36.15	3.15
Private wells Salvatierra (n=10)	10,893	6.6	16.88	27.86	2.56	4,079	5.1	22.08	17.69	4.34
Public wells Salvatierra (n= 21)	9,400	5.0	16.88	31.73	3.38	5,497	4.0	22.08	30.34	5.52
Average	8,978	6.0	16.88	25.37	2.84	6,812	5.9	22.08	25.62	3.99

Financial Performance

Gross return on investment. The construction cost of a water distribution system with the same characteristics of the ARLID can be obtained from current construction work by CNA. This cost is estimated at US$8,000/ha (CNA 1996). Utilizing the annual SGVP per unit of command for the entire year on the district and the two modules, the gross return on investment is 23 percent for the entire district, 28 percent for Cortazar, and 19 percent for Salvatierra. These values compare favorably with those reported by Vermillion and Garcés (1996) for two irrigation districts in central Columbia.

For the private wells, the cost of drilling and installation is of the order of US$52,000/well, which in terms of average command area per well amounts to approximately $3,300/ha. These values combined with the annual SGVP per unit of command for wells give a gross return to investment of 80 percent for the district, 106 percent for Cortazar, and 62 percent for Salvatierra. These values are considerably higher than those obtained from the surface irrigation technology. The high gross return on investment of private wells, combined with the relatively low cost for pumping and maintenance of the wells (table 9), explains the high concentration of wells within a surface irrigation system that has a relatively secure water availability. Although the energy cost will increase dramatically over the coming years as a result of dismantling of energy subsidies, it is expected that the subsidized program to modernize and upgrade existing wells will not be an incentive for farmers to abandon their wells.

Finally, table 10 provides the cost associated with the energy use. The table shows that there is no differential energy cost by sector or module, but that the tariff was increased by 30 percent for the summer season under the Government of Mexico general economic reform policies. As a consequence, pumping costs for the summer were, on average, significantly higher. Pumping costs per unit water in both seasons appear higher for the public wells compared to the private ones as a result of higher inefficiencies associated with poor maintenance conditions.

Financial self-sufficiency. In table 11, the indicator is presented under three slightly different scenarios related to whether subsidies are present or not. A main objective of the IMT program of the Government of Mexico has been the abolition of agricultural subsidies, particularly those related to the O&M of irrigation systems. However, in the case of the ARLID, all of the 115 CNA staff are still paid out of federal funds.

Because only 2 of the 11 modules of the district are included in this report, it is not applicable to add the values by columns. The first row values of the CNA district office reflect the income and the expenses made by CNA to manage the head works and main system of the entire district. The last row represents both total expenses and income for CNA and all 11 modules. The difference between self-sufficiency *with* subsidies and *without* subsidies reflects whether subsidized federal salaries of CNA staff are accounted for or not. The last column provides a measure of either how effective the units are in collecting dues or the commitment of the users in paying their obligations.

From table 11 it is apparent that self-sufficiency for the district as a whole as well as for both modules is very high. Planned fee collection is obtained from the product of the fee per hectare, the number of irrigation

TABLE 11.
Financial self-sufficiency of the Alto Rio Lerma Irrigation District and the Cortazar and Salvatierra modules, 1995 (1995 dollars).

	1	2	3	4	5	6	7	8
						Self-sufficiency		
	Actual O&M expenditures	Subsidized salaries*	Total O&M expenditures	Planned fee collection	Actual fee collection	With subsidies 5/1 (%)	Without subsidies 5/3 (%)	Actual/ Planned 5/4 (%)
CNA district office	426,333	*259,740*	686,073	553,247	535,870	126	78	97
Cortazar module	381,915	0	381,915	300,481	412,954	108	108	137
Salvatierra module	365,551	0	365,551	296,753	335,544	92	92	113
Entire district	2,046,614	*259,740*	2,306,354	1,812,758	2,229,168	109	97	123

*The level of subsidized salaries is an estimate by the authors.

services entitled to, and the area to be cropped. The numbers suggest that expenses are kept under control and that there is good planning in establishing fee levels required to operate the system smoothly. In addition, it would appear that users are committed to the system given the high levels of fee payments. As most WUAs have other sources of income derived, for example from machinery rental or bank interest, the final self-sufficiency values would be even higher than those given. But, because WUAs largely depend on the number of irrigation services they can provide, the 'safety' factor above 100 percent can easily disappear in a dry year. This income dependency on actual water availability can easily jeopardize financial sustainability of the WUAs. This would suggest having a formal emergency fund, which none of the WUAs has.

Environmental Impact

Two indicators were used to assess the environmental impact of irrigation. The first monitors the loss of irrigated area due to negative environmental conditions derived from waterlogging or salinity effects, and the second refers to groundwater fluctuations that can either have deleterious effects on crop production, if the water table rises too close to the surface, or on the water availability for pumping if, on the contrary, the table falls year to year.

In the case of the ARLID as well as the modules no significant evidence was found pertaining to negative environmental effects as a consequence of either waterlogging or salinity conditions.

Groundwater table fluctuations have been monitored and point towards a worrisome situation. In 1995, and following a trend over the last 5 years, static water tables are falling at an average annual rate of 2 to 5 meters (Muñoz 1996), reaching an average depth of more than 100 meters. The high concentration of wells in the State of Guanajuato has resulted in an alarming annual overexploitation of groundwater of 829 MCM for the entire State and 117 MCM for the three aquifers that serve the irrigation district. These volumes correspond to an overexploitation of the aquifers by factors of 1.4 and 1.2, for the State and the district, respectively.

Evaluation of Data Collection Procedures

This section evaluates the data collection procedures that were used to obtain the performance results presented and discussed above. It provides a comparison between the time and resources needed for calculating IWMI's comparative indicators to the effort needed to measure the limited set of selected process indicators.

Comparative indicators. The comparative indicators rely heavily on the availability of secondary data. Once contacts and good working relationships with CNA and the WUAs were established, IWMI was provided with full and unconditional access to the requested data. As CNA and most WUAs use computers to enter and process their data, often, computerized data files could be copied and used. Yet, data collections took more time than the one month anticipated. There are several reasons that explain this.

- For the purpose of cross-checking and control of data quality, where possible, module-level data were aggregated and compared with system-level data. In a large system like ARLID, visiting the 11 modules took a logistical and time-consuming effort. Moreover, often module-level data were not yet entered completely at the time of our visit, and new visits had to be made.
- It took CNA and the WUAs months to process their seasonal data. As a consequence, many visits had to be made to try to update the data required for this report.
- Often, modules used different formats to enter their data, which made it difficult to compare module data and aggregate module-level data to district-level data.
- In a complex system like ARLID total volumes supplied to the modules had to be calculated by adding daily water measurements taken at a large number of control points. This was a time-consuming process.
- Yields and farm gate prices varied from module to module and needed to be cross-checked with data from other sources.
- Converting yields of more than 30 crops to a base equivalent crop at several system levels, for two seasons and for both surface irrigation and wells, required the development and management of large databases.
- Given the differences in climate with the system, climatic data from several stations had to be collected. Visits to more than 10 stations were made to check the quality of the collection procedure used by the stations. Because of the poor quality of the equipment used or awkward location of the station, several weather stations were rejected. Also, the remaining stations appeared to have considerable data gaps.
- Sometimes, historical data were difficult to find, mainly as a result of the three administrative changes that the Ministry of Agriculture and CNA underwent over the last 10 years. As a result, archives and files were lost or data formats had changed frequently, which made historical comparisons difficult.
- Collection of financial data proved to be time-consuming because it took time to understand, interpret, and cross-check the different items and monetary flows presented in the books. In addi-

tion, financial years and agricultural years did not correspond.

Development and modification of the spreadsheets and entering and processing the data took approximately 2 weeks. Data collection and checking were done by the first author and a field assistant, which took about 3 months.[7] A secretary was hired and trained to enter the data, on which approximately 1 month was spent.

In theory, most of the data could have been obtained at the district level (collected and aggregated by CNA). However, it was felt that for the purpose of cross-checking and quality control, data should be collected as much as possible at the primary source. This has improved the reliability of the data presented in this study.

Process indicators. In comparison to the comparative indicators, data collection procedures for applying process indicators are more complex and time- and resource-consuming. A distinction must be made between data required for applying process indicators at the module and district levels, and applying indicators at the level of selected canals and fields.

For the former purpose, in addition to the data required for the comparative indicators, secondary data on dam storage, dam releases, and volumetric concessions, as well as data on planned and reported values were collected. Basically the same problems as described above were encountered. An additional month was estimated to be needed to collect and process the planned and reported values.

Three engineers worked full-time for more than a year to collect primary data and make measurements to apply process indicators at the level of selected canals and fields. In addition, the work in Salvatierra was supported by an M.Sc. student, while in Cortazar a part-time assistant engineer was hired to take the staff gauge readings twice daily and to provide assistance with the calibration of the gauges. Calibration of the staff gauges installed by IWMI proved to be the most time-consuming activity. In addition, much time was spent on visiting the selected fields and taking several flow measurements per field, per irrigation. Calibrating selected wells, measuring flows from wells, taking energy consumption readings, as well as applying the farmer survey to obtain crop budgets, production costs, and cost of water appeared to be a relatively easy activity. Five more months were spent on entering, cleaning, and processing primary data.

Presentation of research process and result. During the data collection process, frequent visits were made to CNA to discuss the data collected. This proved to be an excellent way to verify our preliminary interpretation of the data, encounter new questions, and request for additional data. Several informal meetings were held with management, staff, and farmers of the two selected modules to discuss the same. In addition, IWMI was given the opportunity to attend several hydraulic committee meetings, in which the research progress was discussed with representatives of other modules as well. Finally, three reports with preliminary result were presented at more formal occasions (Kloezen, Garcés-Restrepo, and Marmolejo 1996; Kloezen, Ramirez, and Melgarejo 1996; Kloezen 1997). This provided good opportunities to get feedback from a much wider audience, including system managers, policy makers, and researchers.

[7]Although data from only two seasons are presented here, similar data were collected for the time series data presented in Kloezen, Garcés, and Johnson (1997). Hence, the time input mentioned here is not for the purpose of this report only.

Conclusions

Performance of ARLID

The following are the main conclusions of the performance evaluation in ARLID, based on the application of comparative indicators:

- The irrigation district operated during the winter 1995–96 and the summer 1996 seasons under conditions of relatively abundant water availability. It was possible for the managers to supply the crop water requirements with a good margin of safety, as indicated by the high values of RWS and RIS at different system levels. Generally, RWS and RIS values in Salvatierra are much above the district average levels, while values in Cortazar are slightly below them.

- RWS and RIS values obtained at all levels suggest that well users use more water per hectare than those using canal water. The reasons for this are a relatively low pumping cost as a consequence of subsidized energy tariff, as well as the attempt to avoid risks by not waiting till the rains have started.

- Crop water requirements are calculated on the basis of a single main crop, normally a relatively high water-consuming one in order to be on the 'safe' side. This leads to overcalculation of irrigation depths, especially in Salvatierra, where farmers grow relatively more crops that require less water. This has translated into the high RWS values observed.

- Standardized gross values of production per unit of irrigation supplied or to the water consumed are relatively new concepts and there is a dearth of information that would allow comparison. Some preliminary values have been obtained by IWMI for other systems worldwide and indicate that, generally, values found in ARLID are high, especially for crops grown under wells.

- Established fee levels as well as results of the efforts in collecting those fees adequately cover O&M costs.

- Assessment of environmental impact of irrigation reveals that there seems to be no concern related to adverse waterlogging or salinity conditions in the command areas evaluated. On the other hand, declining water tables are having a negative impact on pumping levels, resulting from overexploitation of the aquifers.

With reference to the first two hypotheses of this report it can be concluded that, generally, application of comparative indicators at the district and module levels provides good information on the differences in quality of water management performance between the modules, seasons, and water sources. Unlike the information currently collected by CNA and the modules, information obtained from comparative indicators could serve to monitor seasonal performance. Although the information points out potential gaps in irrigation management policies (such as the way planned irrigation depths are calculated), it does not provide sufficient information on the reasons for those gaps, nor does it identify possible solutions.

The following are the main conclusions of the performance evaluation in ARLID, based on the application of process indicators:

- *Reliability*. Actual allocation of irrigation water between the modules closely matched the concessioned and assigned allocation. This suggests that at the start of the season, WUAs know how much water will be delivered to them. Establishment of a hydraulic committee at the district level, in which WUAs participate, has given the modules an effective means to monitor the actual supplies against the concessioned and assigned volumes.

- *Flexibility and timeliness*. The hydraulic committee decides on the dates of the opening and closing of the dams. Farmers schedule their irrigation around these days. These irrigation periods are long enough to provide for flexible scheduling within these periods. This is certainly the case under the arranged scheduling arrangement in ARLID, in which farmers request and pay for an irrigation service to be provided on a certain day.

- *Spatial distribution* of RWS values along selected canals is not a major concern to farmers as a result of high actual RWS values. Daily measurements at selected canal and field levels indicate that all farmers receive sufficient water to meet crop requirements. While some variation in spatial distribution exists, there is no bias due to user location (head-middle-tail) within the irrigation network. The reason for this is that farmers closely monitor that they receive the irrigation service they have requested and paid for. At on-farm level, personal interactions between users and ditch tenders play a significant role since this determines both flow size and number of hours that a particular plot may get water.

- *Adequacy*. On-field flow measurements point to high adequacy of water at the field level. The way irrigation deliveries are reported by ditch tenders blurs this high adequacy in official reports. Generally, ditch tenders underreport the volumes allocated to farmers. Furthermore, reported volumes are roughly calculated or even calculated using the planned water depth as a reference. As these reported volumes are the basis of the monitoring of water management from the field up to the district level, this practice has considerable consequences for the quality of the performance monitoring done by CNA and the modules.

Although in theory, water distribution within the module is arranged by volumetric demands, ditch tenders consider the area to be irrigated a more important factor than volume. The priority of area over flows is consistently found at different system levels: from the level of module management (responsible for weekly planning) to the ditch tender at the field level (responsible for daily records), and is conducive to high levels of adequacy, not only to the module, but also within fields.

Process and comparative indicators are complementary. Application of process indicators proved to be useful to gain better understanding of the processes and dynamics of irrigation management in ARLID, as well as the type and quality of several irrigation management services provided by CNA and the WUAs. Furthermore, daily measurements and observations of irrigation management practices at lower system levels appeared to be necessary to understand the nature and the quality of secondary data obtained from module, district, and central levels. For instance, it clearly pointed out the poor quality of the reported data, and consequently the low reliability of CNA´s and the WUA's own monitoring data. These observations strengthened the extra effort IWMI had to take to cross-check the secondary data required for the comparative indicators.

Some Methodological Lessons

This report is one of the first in a series of studies in which the IWMI indicators for irrigation performance are applied. From this study several methodological lessons can be drawn on the applicability of the selected comparative indicators. With reference to the third hypotheses, the following observations can be made.

- Compared to the application of process indicators (which generally requires daily measurements at different system levels), the application of comparative indicators is less time- and resource-consuming. But the large size of the system, the several system levels, the high diversity in cropping patterns, the several irrigation technologies, and the overlap in irrigation seasons of most Mexican irrigation systems, and collecting, verifying, and processing the basic data needed to calculate the comparative indicators proved to be more complex and time-consuming than anticipated.
- The water-based comparative indicators rely on a water balance approach, as it aims to consider non-beneficial ET, flows to groundwater, and so on. However, in many systems reliable secondary data on these components are not available. If comparisons are made across systems or countries it is necessary to know if the excess water in a particular place can be used elsewhere or not. A value of 2.0 is not necessarily better than 2.5 if in the latter case there is no opportunity to utilize the extra resource somewhere else. Compared to other systems, ARLID has good data. Yet, even with a relatively large research team and a good group of collaborators, IWMI-Mexico did not have the expertise, equipment, and budget to better understand the hydraulic position of ARLID within the huge Lerma-Chapala water basin, or the interaction between surface irrigation and recharge of the aquifers.
- In systems like ARLID, cropping patterns as well as yields and prices vary from module to module. For this study we were fortunate that both CNA and all WUAs keep very good seasonal records on these agricultural data. For similar systems, but in different settings or countries with less well-maintained secondary data and trained irrigation staff, applying even the minimum set of comparative indicators will be a difficult task.
- Although Molden et al. (1998) try to combine different seasons to yearly values, in this report it was necessary to apply the indicators to individual cropping seasons since the climatic conditions for the winter and summer seasons are very different in terms of irrigation needs. Aggregation of seasonal information to yearly values does not provide useful information on system performance and potential gaps in irrigation management practices and policies. Likewise, as canal water and groundwater are essentially managed separately it was also necessary to calculate individual indicators per water

source. This meant a substantial increase in time needed to collect and process the data needed.

- An important parameter of the RIS is the effective rainfall. The main irrigation season in ARLID is the winter season, with very little rainfall. Therefore, the method used to calculate effective rainfall hardly affects the RIS value. However, as is shown for the summer season, in seasons with more heavy rainfall, the method to be chosen becomes very important and has to be standardized across systems.

- Comparison of agricultural outputs between ARLID and other systems in Mexico and elsewhere is difficult as this is only based on SGVP, and does not include costs of production. This is particularly the case if systems differ considerably in terms of inputs applied, cost of energy, and irrigation technology used.

The aim of this report was to evaluate the usefulness and applicability of comparative indicators relative to process indicators. A next step in the research process would be to correlate the different process indicators with each other, as well as to correlate types and quality of process performance to comparative performance. This would require a much larger sample of years, modules, fields, and possibly systems and countries. From a methodological point of view, this enforces the need to standardize comparative indicators, which is currently attempted by IWMI. Moreover, it would require standardization of the enormous set of existing process indicators and methodologies to calculate them.

Comparative Indicators Defined

$$\text{Relative Water Supply} = \frac{\text{Total water supply (Irrigation + Total rainfall)}}{\text{Total crop demand at field level}}$$

where, the denominator includes consumptive use, non-beneficial ET, losses to drains, and net flow to groundwater. It is a nondimensional parameter. The consumptive use calculation is standardized by using FAO's CROPWAT method. This variable constitutes a powerful analytical tool as it incorporates the "management" element and farmers' reaction to perceived water availability (Levine 1982).

$$\text{Relative Irrigation Supply} = \frac{\text{Irrigation supply}}{\text{Irrigation demand at field level}}$$

where, the denominator equals the crop demand, less effective rainfall.

$$\text{Water Delivery Capacity} = \frac{\text{Capacity to deliver at (sub) system head}}{\text{Peak consumptive demand}}$$

$$\text{Producton Per Cropped Area (US\$ / ha)} = \frac{\text{Standardized gross value of production}}{\text{Irrigation cropped area}}$$

where, 'standardized' refers to the process of obtaining the standardized gross value of production (SGVP) following a three-step process: i) select a base crop—typically the internationally traded crop covering the largest area—and convert all yields to 'equivalent' on the basis of the specific crop yield multiplied by the ratio of the specific crop price to the base crop, at farm gate; ii) multiply the equivalent yields by the percentage area under each crop to give the production equivalent per hectare of total cropped area for each crop and add them up; iii) multiply the production equivalent by hectare by the world market price of the base crop to obtain the SGVP.

$$\text{Production Per Unit Command (US\$/ha)} = \frac{\text{Standardized gross value of production}}{\text{Command area}}$$

$$\text{Production Per Unit Irrigation Supply (US\$/m}^3\text{)} = \frac{\text{Standardized gross value of production}}{\text{Diverted irrigation supply}}$$

$$\text{Production Per Unit of Water Consumed (US\$/m}^3\text{)} = \frac{\text{Standardized gross value of production}}{\text{Volume of water consumed}}$$

where, the denominator includes ET, non-beneficial ET, and losses to sinks. This indicator measures the contribution of the irrigation activity to the economy related to the consumption of the increasingly scarce water resource. Even under conditions where the water resource is not necessarily scarce, the indicator is useful to judge whether there is enough water that can be utilized downstream or transferred somewhere else.

$$\text{Gross Return on Investment (\%)} = \frac{\text{Standardized gross value of production}}{\text{Cost of irrigation infrastructure}}$$

where, the cost of the distribution system refers to the estimated current cost of construction for an equivalent delivery system.

$$\text{Financial Self–Sufficiency (\%)} = \frac{\text{Water charges}}{\text{Cost of O\&M}}$$

where, water charges include potential revenues from all types of fees related to the water service; and the O&M costs are based on the accounts of either the agency or WUA, whichever is appropriate. Where farmers themselves undertake individual or collective O&M, the costs should be identified and quantified.

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